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Compound Heat Transfer Enhancement in Dimpled Wall Duct Fitted with Coiled Wire Insert

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***Abstract*— To determines the optimum design parameters of the Dimple tube with coiled wire insert using Taguchi experimental design method. In the study, the effects on the heat transfer and pressure loss of the pipe having different parameters like S/D, P/D, cross section of the coiled wire insert and the Reynolds number were investigated. Experiments were carried out between 4000 and 14000 values of Reynolds number. This study analyzed four experimental parameters affecting the heat transfer and pressure loss of dimple tube with coiled wire insert using the Taguchi method. So, the L9 (3^4) orthogonal arrays consisting of these parameters were selected for experimental design. Finally, it was found that the optimum operating condition for the heat transfer and the pressure loss. The results also proved that the Taguchi experimental design method was successfully applied in the study and numerical and experimental results were in very good agreement with each other.**

Keywords— Dimple tube , heat transfer, taguchi method, Reynolds number

I. INTRODUCTION

The need to increase the thermal performance of heat exchangers, thereby effecting energy, material & cost savings have led to development & use of many techniques termed as - Heat transfer Augmentation. These techniques are also referred as - Heat transfer Enhancement or Intensification. Augmentation techniques increase convective heat transfer by reducing the thermal resistance in a heat exchanger.

for the development of improved methods of enhancement. When designing cooling systems for automobiles and spacecraft, it is imperative that the heat exchangers are especially compact and lightweight. Also, enhancement devices are necessary for the high heat duty exchangers found in power plants (i.e. air-cooled condensers, nuclear fuel rods). These applications, as well as numerous others, have led to the development of various enhanced heat transfer surfaces.

In general, enhanced heat transfer surfaces can be used for three purposes:

1) to make heat exchangers more compact in order to reduce their overall volume, and possibly their cost,
2) to reduce the pumping power required for a given heat transfer process, or
3) To increase the overall UA value of the heat exchanger. A higher UA value can be exploited in either of two ways:
    i. to obtain an increased heat exchange rate for fixed fluid inlet temperatures, or
    ii. to reduce the mean temperature difference for the heat exchange; this increases the thermodynamic process efficiency, which can result in a saving of operating costs.

interaction plots for various factors. Multiple linear gray regression analysis technique is used to construct a mathematical model for heat flux and pumping power.

II. EXPERIMENTAL PROCEDURE

- Make sure that connections of the thermocouple are properly attached with the surfaces whose temperature is to be measured.
- Switch on the Heater input and Centrifugal Blower input.
- Using dimmer stat increase the supplied air heater input.
- Start taking readings with time, set as zero
- The blower is started and mass flow rate of air is adjusted suitably with the help of gate valve to have turbulent flow.
- The mass flow rate of air is measured with the help of anemometer.
- Pressure difference between inlet and outlet side of the pipe is recorded with the help of U-Tube Manometer and attached scale.
- Before taking the readings the steady state condition is maintained (approximately 2 hours are required to achieve steady state condition).
- Initially the readings on plain tube and dimpled tube alone were taken. This is to validate and compare the performance of compound approach of dimpled tube and coiled inserts.

- Prepare the Experimental Arrangement mentioned as per the L9 Orthogonal Array each time. For e.g. experiment number 4 in orthogonal array suggests A2B1C2D2 factor and level combination means, (i) A = The ratio of the distance between the test tube wall and coiled wire to tube diameter, s/D = 0.026785 (ii) B = Pitch ratio, P/D = 1 (iii) C = Insert Cross-section = round Φ 3mm and (iv) D = Reynolds Number = 8900

  - The temperature readings T0 (Ambient temperature), T1 (Air temperature at inlet side), T2 (Air temperature at outlet side), and T2 to T7 (temperatures at different location in test section) were recorded with the help of selector switch present on the apparatus.

  - Each set of experiment repeats four times (i.e. nine experiments and four repetitions) to maintain the consistency in the experiment and to reduce the error developed due to extraneous bias.

Factor and Level Combinations

Sr. No.	Factor		Level		
			1	2	3
1	A	The ratio of the distance between the test tube wall and coiled wire to tube diameter, s/D	0.01785	0.026785	0.0357
2	B	Pitch ratio, P/D	1	2	3
3	C	Insert Cross-section	Round Ø 4 mm	Round Ø 3 mm	Square (3 × 3)mm
4	D	Reynolds Number	4450	8900	13400

III. EXPERIMENTAL SETUP

Actual Setup

Figure no.(1) Outline of experimental setup

Forced convection heat transfer apparatus available in institute laboratory for undergraduate heat transfer course is used for this setup. In the existing laboratory setup various modifications (test section) have been made for the heat transfer enhancement analysis of the proposed work. Figure 1, shows the schematic arrangement of the experimental test setup.

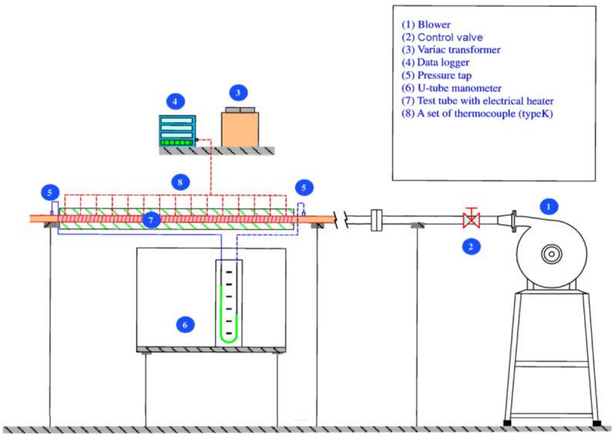


Figure No (2)

The major objective of the proposed research work is to optimize the parameters to achieve the multiple response optimizations of heat flux and pumping power. the dimensions of the coiled inserts (square and circular cross section) and dimple tube are finalized by reviewing the previous literature and discussions with the experts from the industry and academics. The test section (test tube) is made of seamless steel tube with 1000 mm length, inner diameter 36 mm and outer diameter 42 mm. The test pipe is provided with flange ends at both ends. This will facilitate to assemble and disassemble the filament insert conveniently. The tube was heated by continuously winding flexible electrical wire (heater of 500 watt) which provides the uniform heat flux boundary condition. The electrical output power was controlled by a variac transformer to obtain a constant heat flux along the entire length of the test section and by keeping the current less than 3 amp. The outer surface of the tube was well insulated to minimize convective heat loss to surroundings, and necessary precautions were taken to prevent leakages (working fluid as well as electric current) from the system. The two thermocouples (copper-constantan), one at inlet side and another at outlet side of the test section and remaining six on the surface of the test tube (approximately 165 mm apart) were placed to measure the temperature with the help of multi-channel temperature measurement unit. The filament insert assembly (all made up of aluminum) is snug fitted inside the test tube.The details of filament insert assembly are given below;

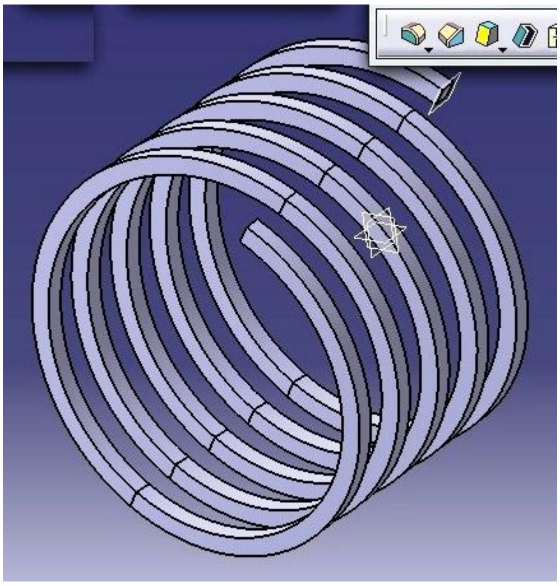


Figure no. (3) Coiled Insert (Square Crosse-section) Solid Model

- Outside Diameter = 32 mm
- Cross section = Square (3×3) mm
- Inside Diameter = (32-6) = 26 mm
- Length = 1000 mm
- Material = Plain Carbon Steel
- Pitch;
- (p/D = 1) pitch = 32 mm
- (p/D = 2) pitch = 64 mm
- (p/D = 3) pitch = 96 mm

Three different pitch value square cross section coiled inserts are prepared.

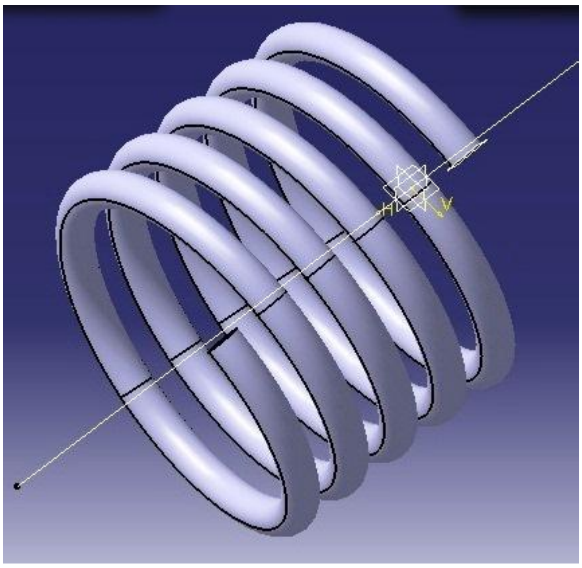


Figure no.(4) Coiled Insert (Circular Crosse-section) Solid Model

- Outside Diameter = 32 mm
- Cross section = Φ 3 mm and Φ 4 mm
- Inside Diameter = (32-6) = 26 mm and
- Inside Diameter = (32-8) = 24 mm
- Length = 1000 mm
- Material = Plain Carbon Steel Pitch;
- (p/D = 1) pitch = 32 mm
- (p/D = 2) pitch = 64 mm
- (p/D = 3) pitch = 96 mm
- Total six circular cross section coiled inserts are prepared of three different pitch values and 2 different diameters.

Figure no. (5) Sample Coiled Inserts (Circular and Square Cross-section with different pitch)

Total six circular cross section coiled inserts are prepared of three different pitch values and 2 different diameters.

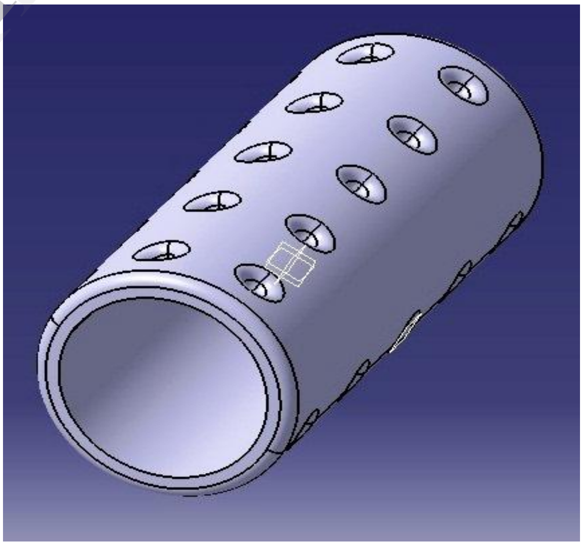


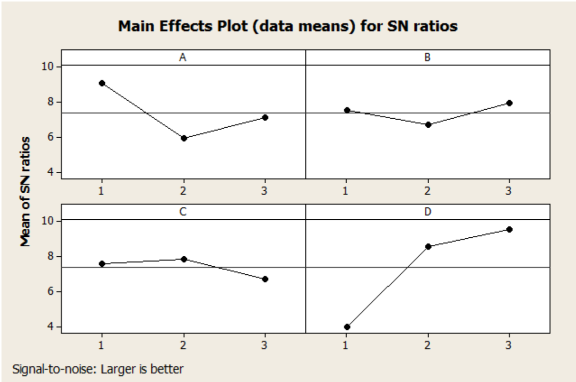
Figure no. (6) Dimpled Tube - Solid Model

- Outside Diameter = 42 mm
- Inside Diameter = 36 mm
- Length = 1000 mm
- Dimple Geometry
- Cross-section = Circular
- Diameter = 4 mm
- Depth = 2 mm
- Number of dimples present on the periphery at the cross-section = 6 i.e. 600 apart.

The dimples are made 40 mm apart of each other Pitch = 40 mm

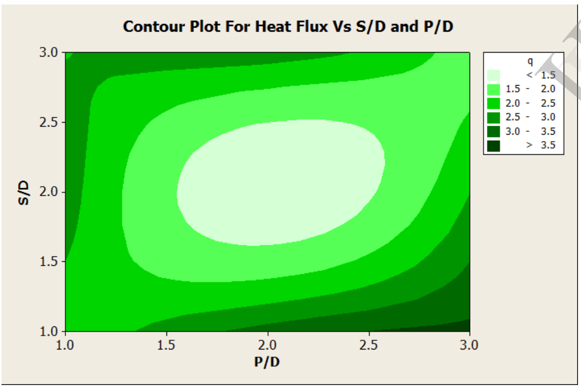
Figure no. (7) Dimpled Tube

IV. RESULT AND DISCUSSION



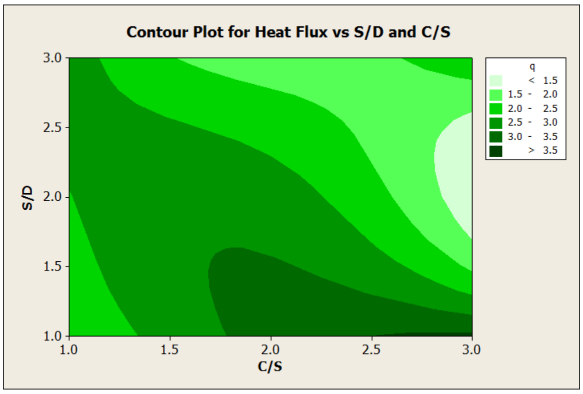
Signal to noise ratio for heat flux

From the figure of Main Effect Plot the optimum factor combination; A1B3C2D3
Mean change = 3.7575 and S/N Ratio= 12.2916 (verified with MINITAB)



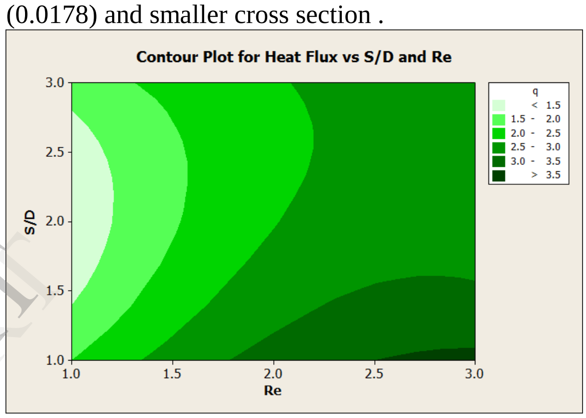
Plot no.(1) Heat Flux Vs S/D and P/D.

Counter plot for Heat Flux Vs S/D and P/D
From the Counter plot for Heat Flux Vs S/D ratio and P/D ratio it is observed that higher heat flux can be obtained for both S/D ratio (0.0175) and (0.02678) and for all ratio of P/D



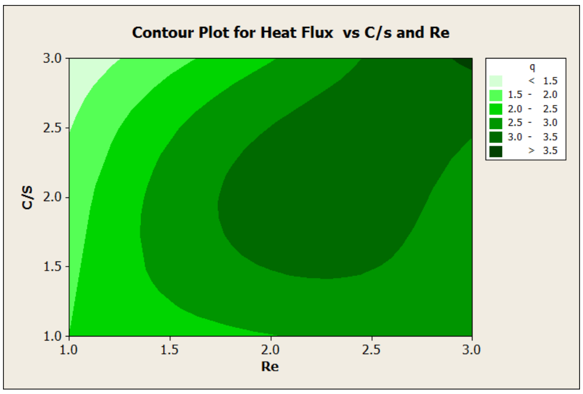
Plot no(2) Heat Flux Vs S/D and C/S .

Counter plot for Heat Flux Vs S/D and C/S
From the Counter plot for Heat Flux Vs S/D ratio and cross section it is observed that higher heat flux can be obtained for S/D (0.0178) and smaller cross section .



Plot no (3) Heat Flux Vs S/D and Re.

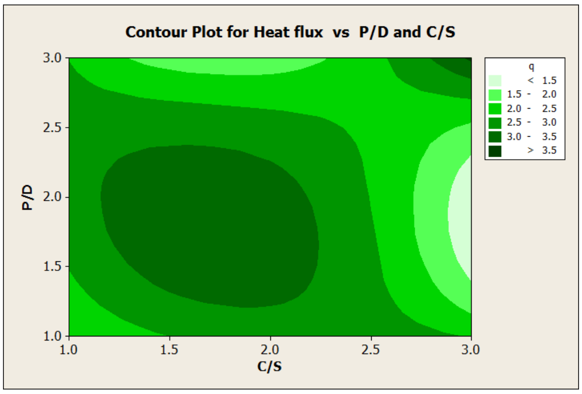
Counter plot for Heat Flux Vs S/D and Re
From the Counter plot for Heat Flux Vs S/D ratio and Reynolds number it is observed that higher heat flux can be obtained for lower S/D ratio(0.0175) and higher Reynolds number (13400).



Plot No(4) Heat Flux Vs C/S and Re.

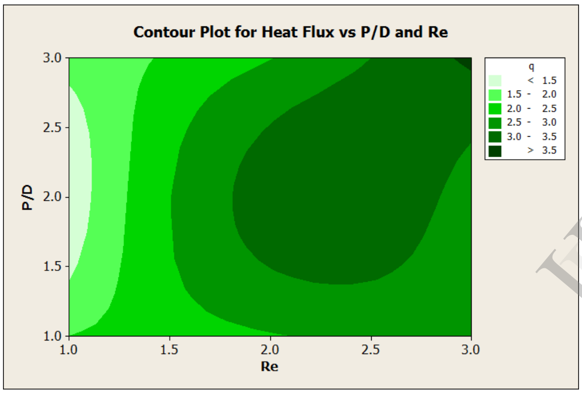
Counter plot for Heat Flux Vs C/S and Reynolds number
From the Counter plot for Heat Flux Vs cross section and Reynolds number it is observed that higher heat flux can be

obtained for both cross section (Φ4mm) and Square(3 × 3) mm both the Reynolds number 8900 and 13400.



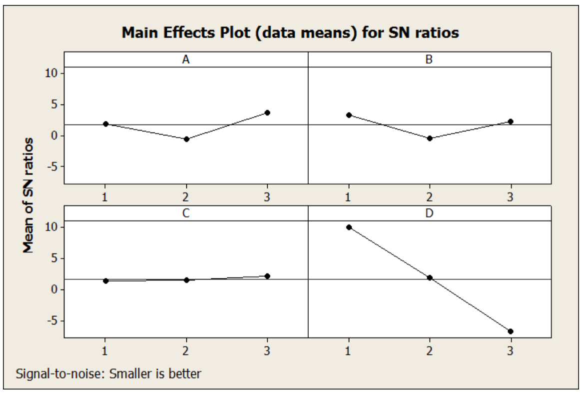
Plot no (5) Heat Flux Vs P/D ratio and C/S.

Counter plot for Heat Flux Vs P/D ratio and C/S
From the Counter plot for Heat Flux Vs P/D ratio and cross section it is observed that higher heat flux can be obtained for both P/D ratio (0.0178) (0.026785) and both the circular cross section Φ3 mm and Φ4mm .



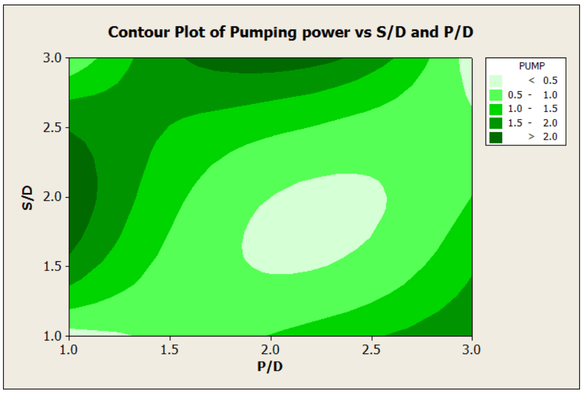
Plot no (6) Heat Flux Vs P/D ratio and Re.

Counter plot for Heat Flux Vs P/D ratio and Re
From the Counter plot for Heat Flux Vs P/D ratio and Reynolds no it is observed that higher heat flux can be obtained for both P/D ratio (0.026785) and (0.0357) and both the higher Reynolds number (8900) and (13400)



Signal to noise ratio for pumping power.

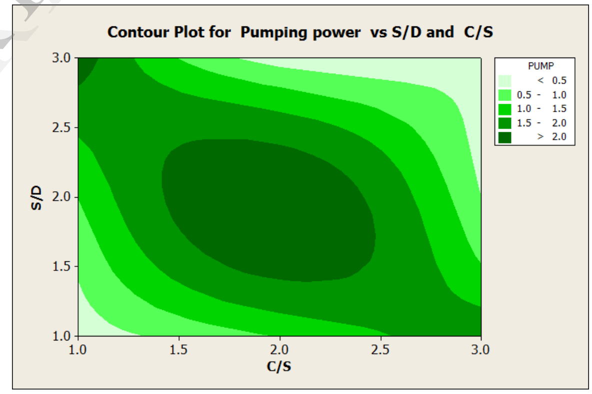
From the figure of Main Effect Plot the optimum factor combination; $\mathbf{A_3B_1C_3D_1}$
Mean change = 0.00881 and S/N Ratio= 18.3388 (verified with MINITAB)



Plot no (7) Pumping power Vs S/D and P/D ratio.

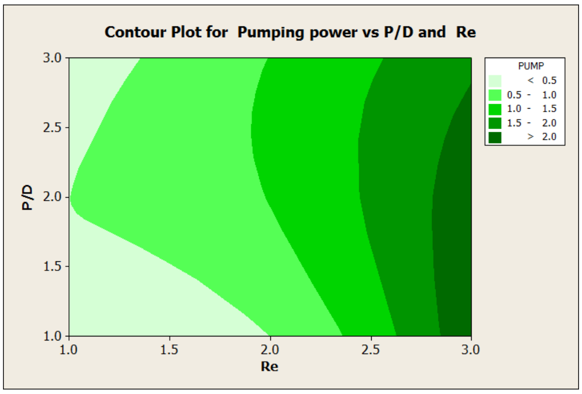
Counter plot for Pumping power Vs S/D and P/D ratio
From the Counter plot for Pumping power Vs S/D and P/D ratio it is observed that higher heat flux can be obtained for the

1) S/D ratio (0.0175) and P/D ratio (1).
2) S/D ratio (0.02678) and P/D ratio (2).



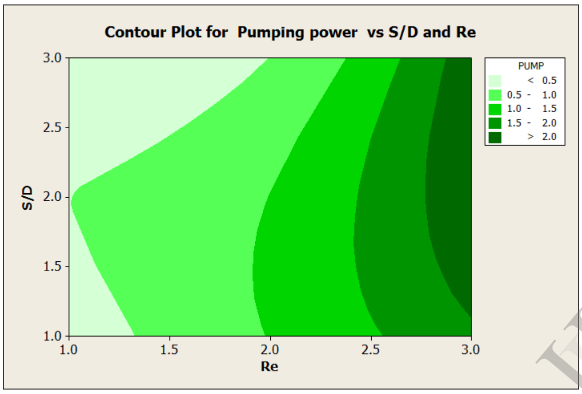
Plot no (8) Pumping power Vs S/D and C/S.

Counter plot for Pumping power Vs S/D and C/S
From the Counter plot for Pumping power Vs S/D and Cross section it is observed that higher heat flux can be obtained for the S/D ratio (0.0267) and circular cross section Φ3mm.



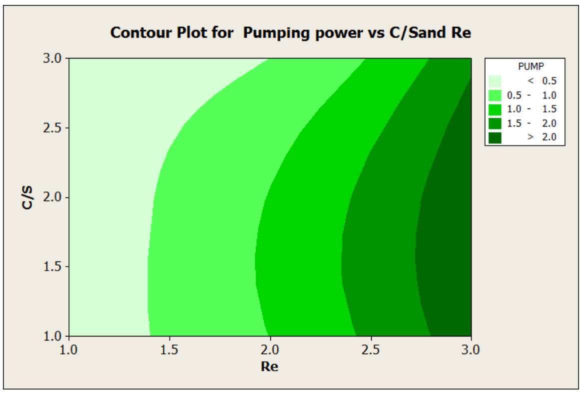
Plot no (9) Pumping power Vs P/D and Re.

Counter plot for Pumping power Vs P/D and Re.
From the Counter plot for Pumping power Vs P/D ratio and Reynolds number it is observed that higher heat flux can be obtained for the two ratio (1) and (2) and Reynolds number (13400).



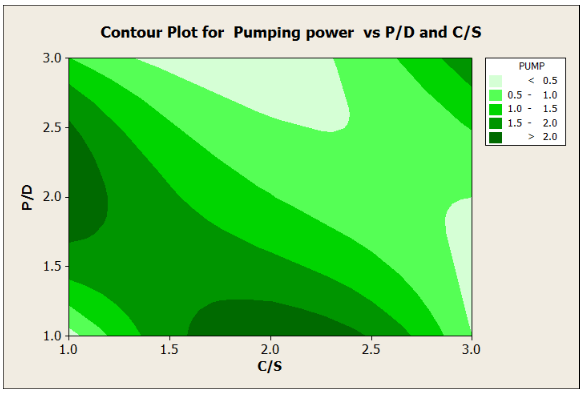
Plot no (10) Pumping power Vs S/D and Re

Counter plot for Pumping power Vs S/D and Re
From the Counter plot for Pumping power Vs S/D and Reynolds number it is observed that higher heat flux can be obtained for the all S/D ratio and Reynolds number (13400).



Plot no (11) Pumping power Vs C/S and Re.

Counter plot for Pumping power Vs C/S and Re.
From the Counter plot for Pumping power Vs cross section and Reynolds number it is observed that higher heat flux can be obtained for the two cross section Φ3 mm and Φ4mm and Reynolds number (13400).



Plot no (12) Pumping power Vs P/D and C/S.

Counter plot for Pumping power Vs P/D and C/S.
From the Counter plot for Pumping power Vs P/D and Cross section it is observed that higher heat flux can be obtained for

1) P/D ratio (2) and cross section Φ4mm.

P/D ratio (1) and cross section Φ3mm

V. CONCLUSION

From Taguchi analysis for heat flux (q) the optimum combination of factor and level which yields the heat transfer enhancement is A1B3C2D3 means
A1: The ratio of the distance between the test tube wall and coiled wire to tube diameter, s/D = 0.01785
B3: Pitch ratio, P/D = 3
C2: Insert Cross-section = Round Ø 3 mm
D3: Reynolds Number = 13400

Similarly Taguchi analysis for Pumping Power the optimum combination of factor and level which yields the minimum pumping power requirement is A3B1C3D1 means
A3: The ratio of the distance between the test tube wall and coiled wire to tube diameter, s/D = 0.0357
B1: Pitch ratio, P/D = 1
C3: Insert Cross-section = Square (3 × 3) mm
D1: Reynolds Number = 4450

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